First imaging of cold magnesium ion clouds in SpecTrap*

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In recent years, sympathetic cooling has been established as an important tool for the study of exciting quantum phenomena and applications, ranging from microwave quantum logic gates [1] to ultracold chemical reactions [2]. It is mostly used when other cooling methods such as Doppler laser cooling cannot be applied. This also holds for Highly Charged Ions (HCIs), which are the subject of our current investigations at SpecTrap. We will therefore exploit a cooling strategy based on laser cooled singly charged magnesium ions for cooling any species of HCIs down to the mK regime for high precision laser spectroscopy experiments.

The experimental apparatus, the preparation scheme, and first experimental results of laser cooled Mg^+ are described in detail in [3]. In brief, singly charged magnesium ions are produced in an electron impact ion source and are subsequently transfered in bunches of 1–10 μs at an energy of 200 eV into a cylindrical Penning trap. By dynamically switching the trap electrodes it is possible to stack multiple ion bunches. The precise timing even allows isotope selective loading by this means. All experimental parameters, such as electrode or ion optic voltages, are controlled by our newly developed experimental control system, which was successfully tested in 2012.

After completion of the loading procedure, the ion cloud is efficiently cooled by 280 nm laser light irradiated in axial direction. For this purpose, a new seed laser was installed to provide more than 10 mW ultraviolet laser light after frequency quadrupling. A frequency stability of the seed laser of a few hundred kHz on a long-term scale was achieved by locking it to a high-precision wavemeter. Fluorescence detection of the scattered cooling light is performed in radial direction. During the cooling phase of approximately six seconds, the ionic sample undergoes a transition to a strongly coupled state. The rearrangement of the ion cloud becomes apparent in form of a precooling peak visible in the fluorescence spectra while scanning across the resonance [3]. Detailed analysis of the obtained fluorescence signal reveals an upper limit for the ion temperature of roughly 60 mK.

Usually, the laser frequency is tuned to the closed $\left|3^2\mathrm{S}_{1/2}, \mathrm{m_j} = -1/2\right\rangle \rightarrow \left|3^2\mathrm{P}_{3/2}, -3/2\right\rangle$ transition to ensure permanent cooling of the confined ionic ensemble. By observing the fluorescence signal, the lifetime of the magnesium ions in the trap was estimated. A single measurement of the lifetime shows that the ion cloud could be stored for 75 minutes without significant losses.

Additionally to the fluorescence detection with photomultiplier tubes, a UV-CCD camera was used to image the ion cloud. In figure 1 a sequence of four images of the laser cooled ion cloud is depicted. It shows a compression of the cloud during the cooling phase. By varying the trap voltages, precise control of the spatial position of the ion cloud was possible and even the manipulation of the ion cloud density might be possible using the rotating wall technique [4]. In future, an improvement of the imaging system will help us to study in more detail the ion dynamics of low-Z ions, HCIs and their mixtures in the Penning trap.

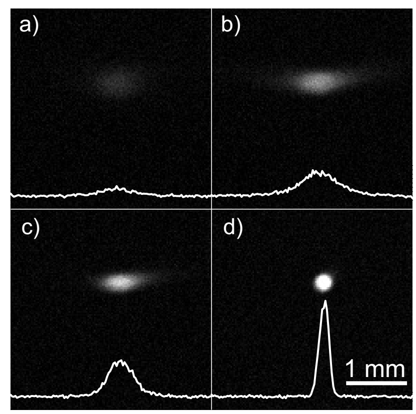

Figure 1: Images of the ion cloud during laser cooling together with the corresponding radial profiles.

In summary, the experimental results show that we can prepare an ideal source of cold and dense singly charged magnesium ions, by optimizing the vacuum conditions, implementation of an experimental control system and optimizing the existing laser system. As soon as the beamline from the HITRAP facility to SpecTrap is finished, first high precision spectroscopy measurements on HCIs will be possible.

References

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